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SUMMARY OF RESULTS OF PRESSURE COEFFICIENT CALCULATIONS FOR A SPHERICAL-TIPPED TANGENT-OGIVE BODY

By

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ABSTRACT. A review of the results obtained in preliminary work conducted by the Naval Ordnance Test Station to develop procedures for the calculation of pressures on practical body shapes using currently available theories and computing methods is presented. A comparison of the calculated results with experimental data is made to check the validity of the procedures.

U.S. NAVAL ORDNANCE TEST STATION

China Lake, California

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FOREWORD

This report presents the results obtained from part of a continuing investigation of the pressure distribution on bodies of arbitrary shape which are typical of those used in current missile configurations.

The analytical portion of this work was carried out at the Naval Ordnance Test Station under Bureau of Naval Weapons WEPTASKS RMGA-41-039/216-1/F009-10-001 of June 1960 and RMMO-53-034/216-1/F009-10-002 of August 1961. The experimental work reported here was conducted under Bureau of Naval Ordnance Task Assignment NO-502-726/62020/01-060 of July 1958.

This report is released at the working level for informational purposes only.

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Special mention is given to the members of the former Aero/Astrodynamics Section and their associates of the Douglas Aircraft Company, Santa Monica, California for preparing and running the method of characteristics portions of the pressure distribution calculations. Their cooperation in adapting their digital computing programs to the requirements of this study resulted in considerable savings in the time required for the completion of the work reported here.

Also, much credit is given to David F. Johanson of the Weapons Development Department, NOTS, for his work in the preparation of the experimental data which were drawn upon so heavily for the comparisons made in this report.

INTRODUCTION

The need for methods of predicting the pressure distribution on moving bodies of revolution has been a long standing one. The information is essential in the estimation of aerodynamic stability and heating effects of missiles and other flight vehicles.

In the past, a large number of theoretical methods has been developed to describe the pressures on bodies in flight, using numerous mathematical and physical approaches in the analysis. Unfortunately most, if not all, of these methods have been suitable for application to a limited range of physical conditions or to idealized body shapes. These theories and procedures, though quite valid individually, can rarely be used in the calculation of the pressures on complete practical body shapes over the wide range of conditions met in practice.

The material presented in this report outlines the results of some preliminary work which was performed at the Naval Ordnance Test Station (NOTS) in an attempt to develop techniques for the calculation of pressures on practical body shapes using currently available theories and computing methods. The approach to the problem is based on fitting together the different calculating procedures in such a way as to permit their being applied over the portions of the body configurations which correspond to the shape for which the theories were derived. While this technique has been applied by many in a piece-meal fashion, a systematic procedure for accomplishing the desired pressure distribution calculations for a complete body has never been explicitly presented in a convenient form. The work reported here is part of the early phases of a continuing effort to develop a practical approach to the problem of pressure calculations for a representative missile body configuration.

METHOD OF INVESTIGATION

The initial portions of the pressure distribution study consisted of two major parts. The first was the experimental program which served to provide data for use in checking the results of the theoretical calculations. The second part consisted of the exploratory computations which provided an insight into the techniques necessary for mathematically calculating the pressures on a body of revolution.

These initial studies were conducted in a relatively elementary fashion. The experiments and calculations all used a basic simple body configuration as a common base for the various phases of the over-all study. The shape was selected to simulate a typical missile body which was somewhat idealized to avoid complicating the computational processes by the introduction of abrupt discontinuities in the contours.

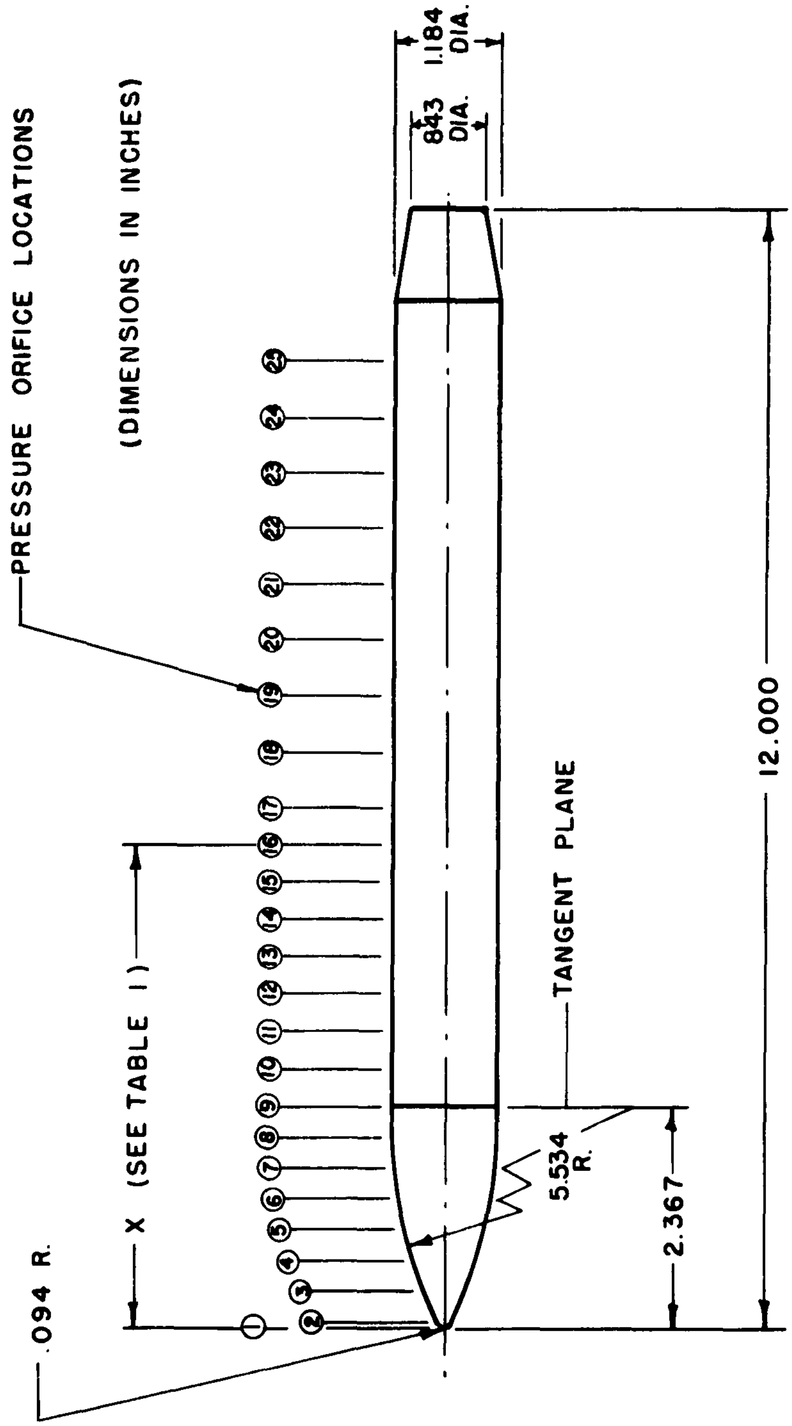

FIG. 1. Model Configuration.

Figure 1 shows the body to be a combination of an ogival nose with a spherical tip, a long cylindrical body, and a short truncated conical boattail. This combination of body elements is very similar to individual idealized shapes used in many theoretical solutions for pressure distributions, making the computational portion of this study simpler than if some purely arbitrary form was used. The spherical tip on the nose serves to introduce into the analysis a detached shock wave in the supersonic flow calculations.

EXPERIMENTAL DATA

The experimental portion of this study was conducted in the 40- by 40-centimeter supersonic wind tunnel of the Naval Ordnance Laboratory (NOL), White Oak, in Silver Spring, Maryland. The wind tunnel tests covered a speed range of Mach 0.75 to 4.84 at angles of attack of -10, 0, and +10 degrees. The data from the Mach 1.53, 2.17, 3.24, and 4.84 runs are presented for purposes of comparison with theoretical predictions. The curves showing the data of the remaining Mach numbers are presented in the Appendix.

Well standardized experimental procedures were used in conducting the wind tunnel tests. In the data reduction, the pressure coefficient C_p was defined as $C_p = \Delta p/q$ where Δp is the change in pressure with respect to the free-stream static pressure, and q is the dynamic pressure. This definition is in accordance with the expression in current usage. The model configuration used in the experiment is shown in Fig. 1, and the locations of the surface pressure taps are listed in Table 1. The model was sting-mounted on the NOL balance sector with the pressure taps connected to the externally located pressure-recording instruments with flexible tubing. The model, sting, and pressure tubing are shown in Fig. 2 and 3. The data obtained were reduced to coefficient form through the use of the standard numerical data processing methods. A summary of the results of the wind tunnel tests is presented in Ref. 1.

DISCUSSION OF PRESSURE CALCULATIONS

The first obvious approach to the calculation of the pressures on a blunt-tipped body is to select an equivalent pointed body which may be used in the application of theoretical procedures such as those given in Ref. 2 and 3 which have been derived for sharp-nosed bodies. For a body of the proportions shown in Fig. 1, where the blunt tip is small in comparison to the rest of the nose, this technique can produce fairly accurate results for the pressures on the ogive. With the exception of the stagnation point, which normally must be treated as a singularity anyway, this method naturally cannot be expected to predict the pressures on the blunt tip with any real accuracy. The tip can be treated separately using methods such as those of Ref. 4 and 5.

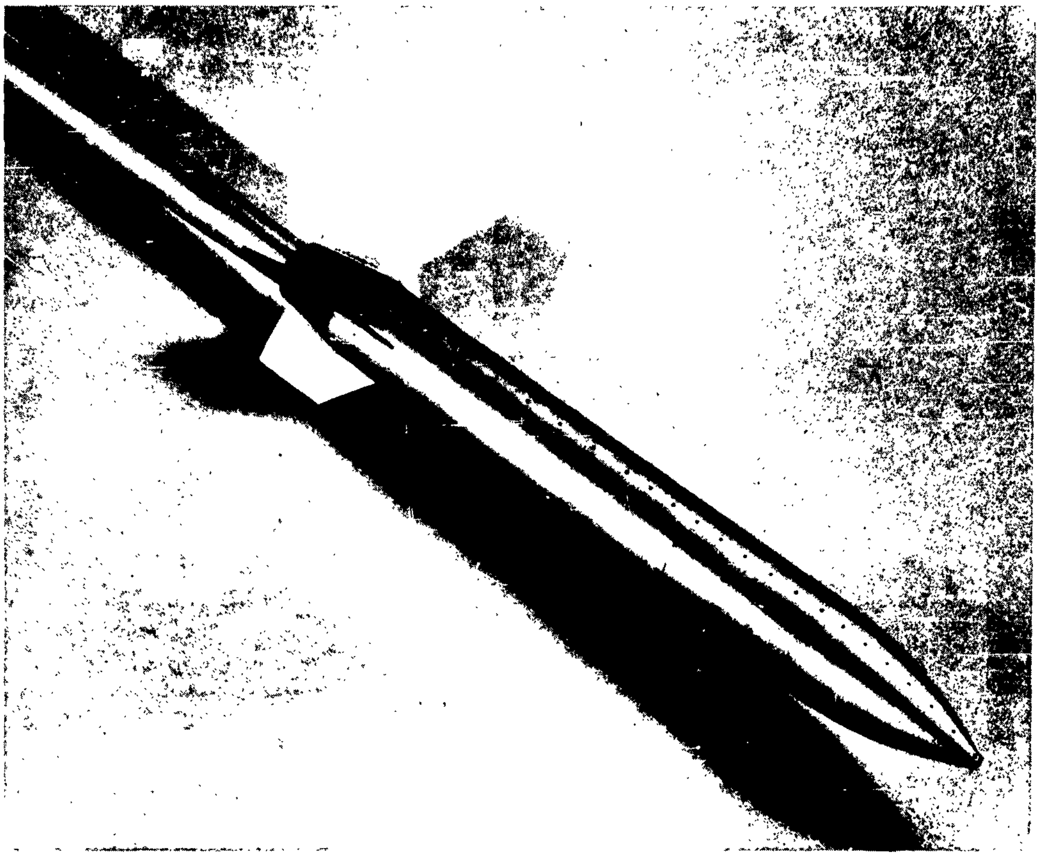

FIG. 2. Model Used in Wind Tunnel Tests.

The validity of this empirical method of determining pressure distribution has been checked with the results of the NOL wind tunnel data. The theoretical data were interpolated from a family of curves for tangent-ogive shapes and various Mach numbers which were given in Ref. 6, where the results of a computing program based on Van Dyke's second-order theory (Ref. 2) were presented. Comparisons are made with the NOL data for Mach numbers of 1.53 and 2.17 using curves obtained by interpolation to correspond to the body shape of Fig. 1.

Figures 4 and 5 show that the results obtained by substituting a pointed body in place of the blunt body in the estimation of the pressures on the ogive are in excellent agreement with the experimental data. As to be expected, there is an element of doubt about the accuracy near the tip of the nose since the experimental-data points in that region show some unexplained variations which do not conform to the trends exhibited in the rest of the data. Both Fig. 4 and 5 indicate that the theoretical method overestimates the pressures in the region near the juncture of the body and ogive. This effect has been noted (Ref. 6) for the pointed

FIG. 3. Assembled Model, Sting, and Pressure Leads.

ogive shapes for which the theory was derived and is apparently not due to the application of this theory to the slightly blunted body used in this study.

Although agreement between theory and experiment was good in this case, it is unlikely that such excellent results will be obtained with bodies of greater bluntness since the theory used in this example and most of the other theoretical methods for pointed bodies are derived from an assumption of conical flow at the tip, while a fairly blunt body has a highly distorted flow field at the nose. This distortion introduces an error in the calculated pressures which cannot be accommodated by the current theories.

When the bluntness of the nose is such that severe distortion of the streamlines at the tip occurs, then the method just described cannot adequately predict the pressures on the body surface. The pressure distribution on the nose of a blunt body cannot be conveniently calculated in one continuous solution; the blunt tip with its attendant detached shock

TABLE 1. Pressure Orifice Stations

D = diameter = 1.184 inches

Station	Pressure orifice coordinates, inches		Station	Pressure orifice coordinates, inches	
	X	X/D		X	X/D
1	0	0	16	5.167	4.364
2	0.055	0.046	17	5.567	4.702
3	0.385	0.325	18	6.167	5.209
4	0.715	0.604	19	6.767	5.715
5	1.045	0.883	20	7.367	6.222
6	1.375	1.161	21	7.967	6.729
7	1.705	1.440	22	8.567	7.236
8	2.035	1.719	23	9.167	7.742
9	2.367	1.999	24	9.767	8.249
10	2.767	2.337	25	10.367	8.756
11	3.167	2.675			
12	3.567	3.013			
13	3.967	3.351			
14	4.367	3.688			
15	4.767	4.026			

wave in supersonic flow and with a region of subsonic flow immediately downstream requires a mathematical treatment that can accommodate the distortion of the streamlines and the large entropy gradients.

A technique which can be applied in the calculation of such a flow field is to initially determine the conditions at the nose by some means such as those of Ref. 4 or 5, and then use the results as the input conditions for analysis of the flow further downstream. This method was successfully used in the calculations of pressure coefficients for the body of Fig. 1.

These particular calculations were made by Douglas Aircraft Company, Santa Monica, California under a contract for special computing services in connection with the estimation of pressures and heat transfer characteristics of missiles being developed at NOTS. The availability of the Douglas computing program was convenient in that they eliminated the necessity of preparing similar preliminary programs at NOTS prior to the development of computing programs better suited to the needs of this Station.

The digital computing program used by Douglas is based on the Method of Characteristics as the primary analytical approach in the

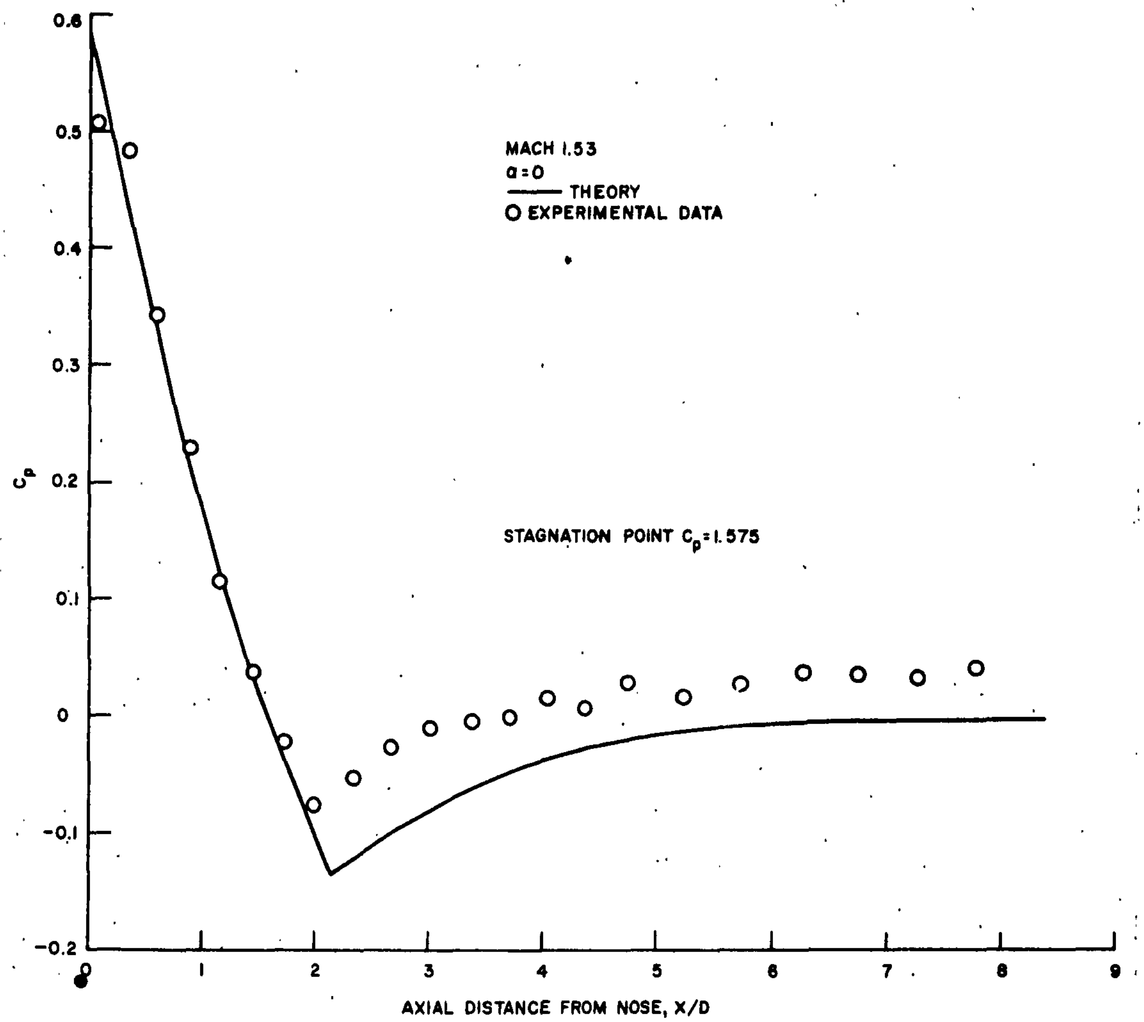

FIG. 4. NOL-Van Dyke Curves Mach 1.53, $\alpha = 0$.

calculation of the flow field about the body. The Method of Characteristics program, coupled with a separate program for the determination of the flow at the tip of the nose, permits the numerical calculation of the flow field in which the inviscid fluid dynamic equations are solved. However, two important restrictions of the program are made; i.e., the configuration must be axisymmetric or two-dimensional and the flow must be a perfect inviscid gas with a constant ratio of specific heats. Details of the Douglas program are given in Ref. 7.

The results of the calculations by Douglas are presented in Fig. 6 through 9 in the form of curves. Data points from the NOL wind-tunnel tests are also shown for comparison. In order to avoid difficulties with the program in the digital computing machine, only the pressure

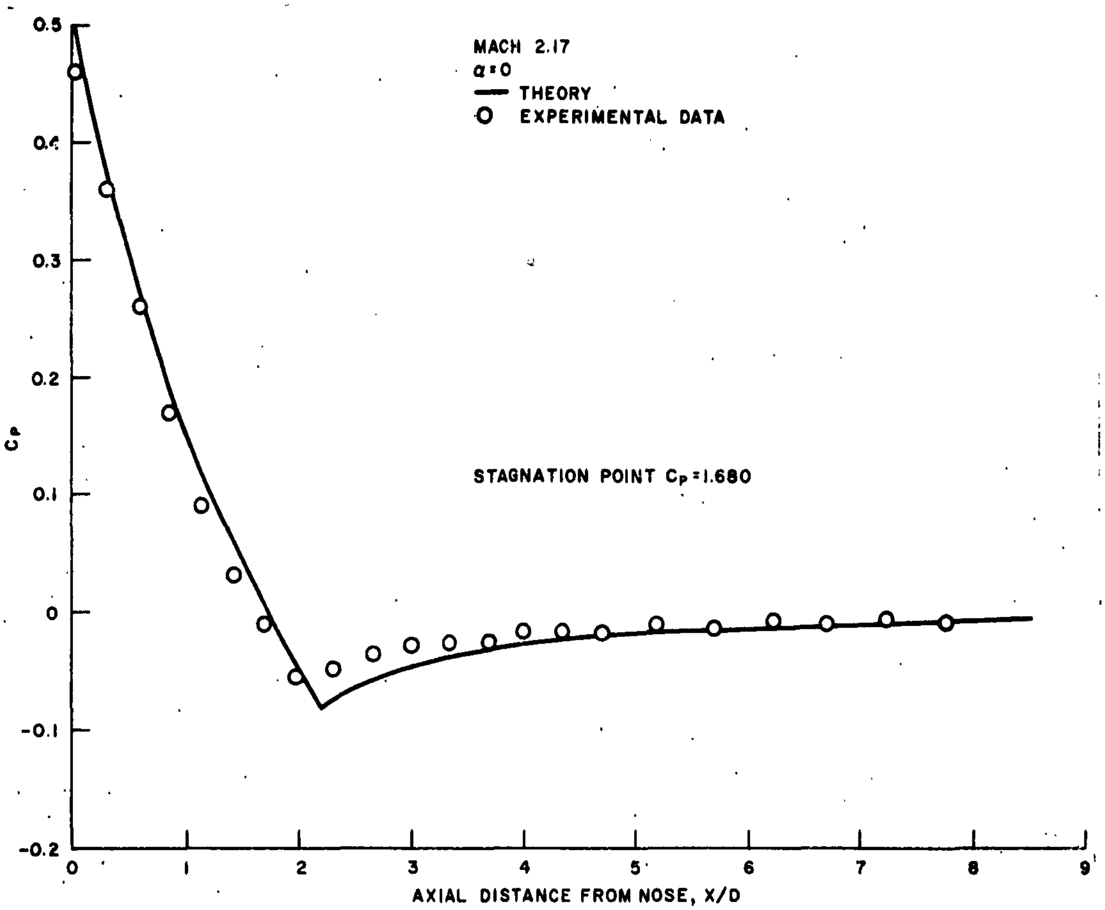

FIG. 5. NOL-Van Dyke Curves Mach 2.17, $\alpha = 0$.

distributions for Mach 3.24 and 4.84 were calculated. These curves show that the process of fitting two different computing programs together to develop the pressure and flow field on a blunt body can be done successfully and accurately. The fit of the theoretical and experimental data is excellent at small angles of attack. Since no experimental data were taken for points on the spherical tip, no comparison can be made although the irregular shapes of the curves in the regions corresponding to the tip can be taken as an indication of significant errors.

The curves for the larger angles of attack show progressively greater errors as the angle is increased. As stated previously, this trend is not unexpected since the Method of Characteristics solution is derived for axisymmetric and two-dimensional flows only. The manner in which the computing procedure was applied to the angle-of-attack cases was to take the ordinates of the body in the direction and plane of the angle of displacement and to rotate them about an axis of symmetry running through the nose and in the direction of the free stream flow. The body of revolution thus developed was then used in the calculations

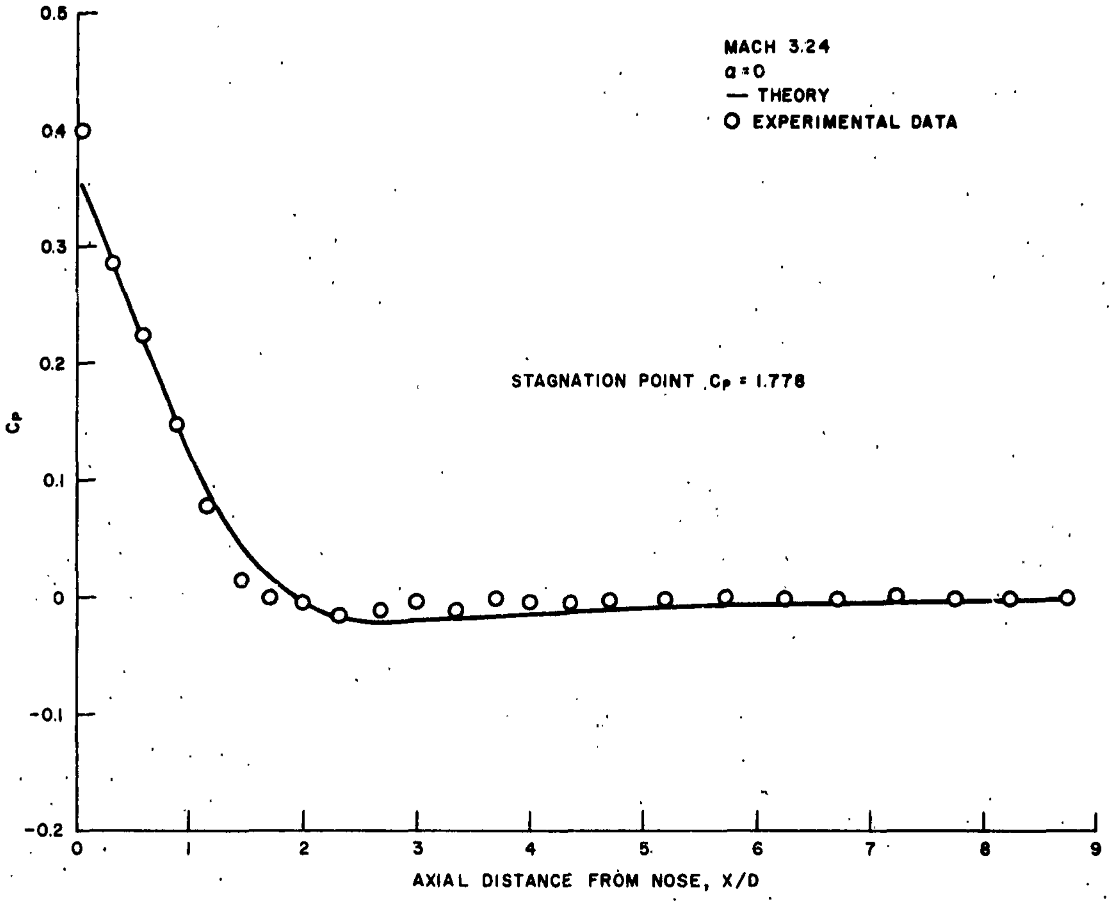

FIG. 6. Characteristics Solution Mach 3.24, $\alpha = 0$.

as was done for the axisymmetric bodies. It is apparent that this procedure will lead to significant errors in the magnitudes of the pressures on the windward side of the body and, in a minor way, introduce errors by distorting the body shape. Figure 10 shows the relative errors produced by this technique.

CONCLUSIONS

On the basis of the preceding discussion, it is seen that the process of fitting together the results of several computing procedures in tandem may be a valid approach to a solution of the problem of calculating surface pressures on a given blunted body of revolution. The experience with the preliminary work reported here indicates that suitable computing procedures can be developed for this purpose so that pressure distribution calculations can be made on digital computing

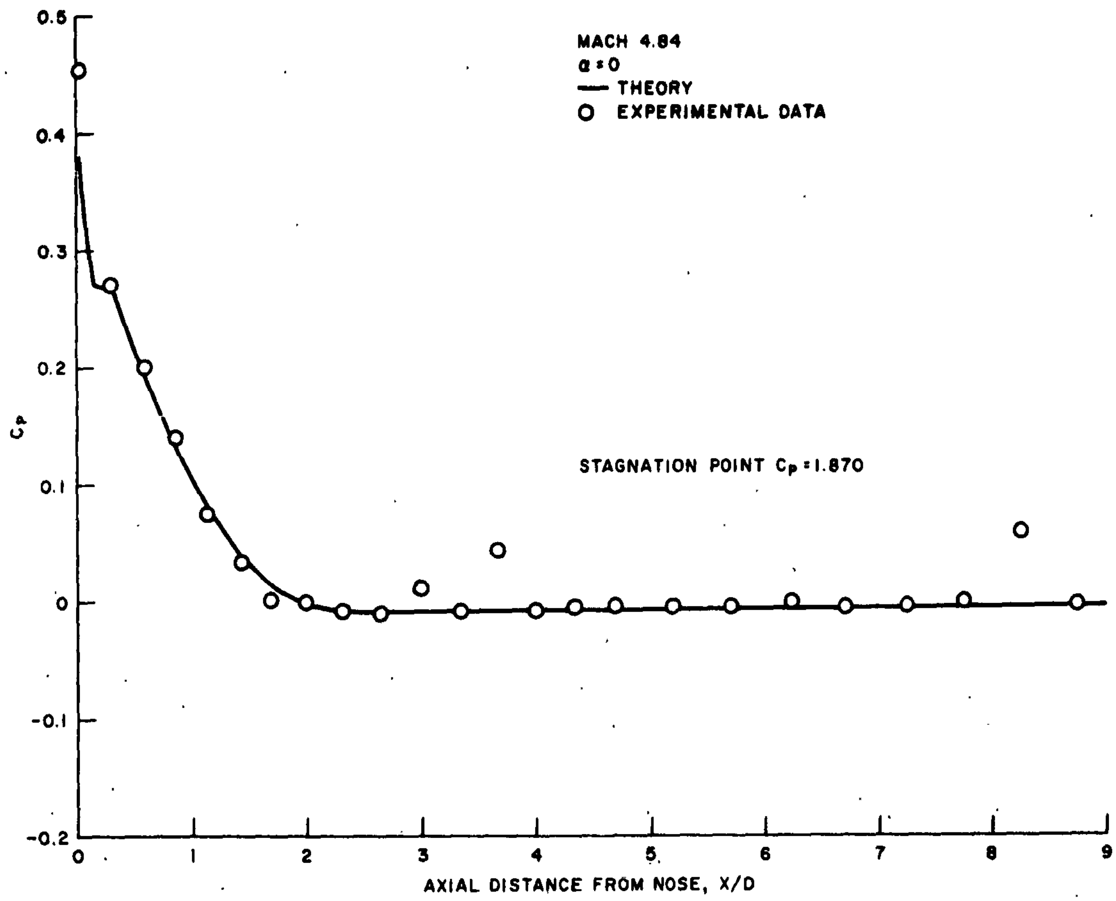

FIG. 7. Characteristics Solution Mach 4.84, α = 0.

machines in a routine manner for bodies of revolution composed of common geometric shapes. The availability of such a program will obviously be of great value in the calculation of aerodynamic heating and force estimations.

To achieve this end, it is apparent that several important points must be investigated, such as the question of how the analytical computing procedures can be adapted to the case of a blunt body at an angle of attack, and whether the procedure described can be applied to bodies of revolution of greater bluntness and still obtain the desired accuracy. These latter objectives, fortunately, can be considered in the course of developing the over-all computing procedures. A parallel problem also exists in the question of whether this type of procedure can be used in the calculation of subsonic and transonic pressure distributions.

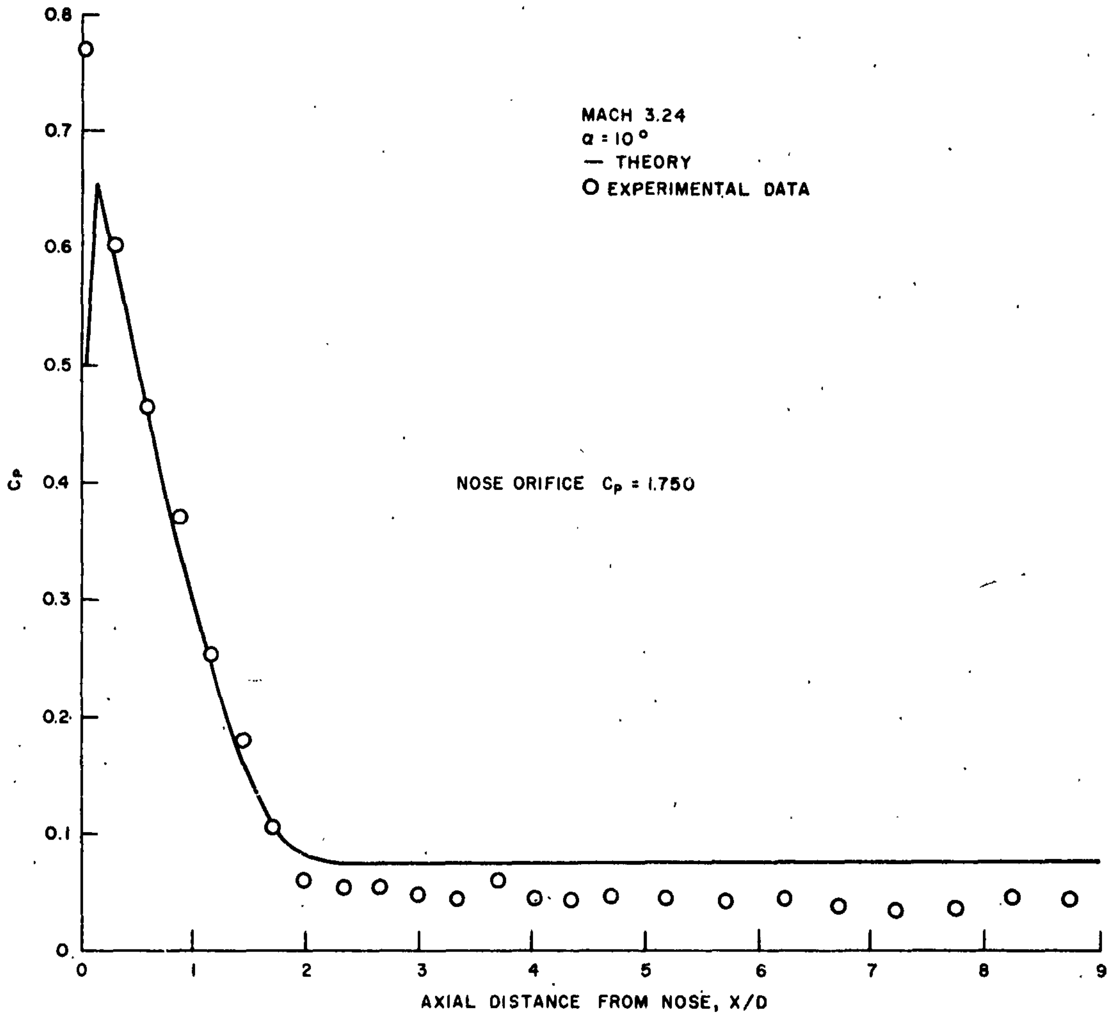

FIG. 8. Characteristics Solution Mach 3.24, α = 10°.

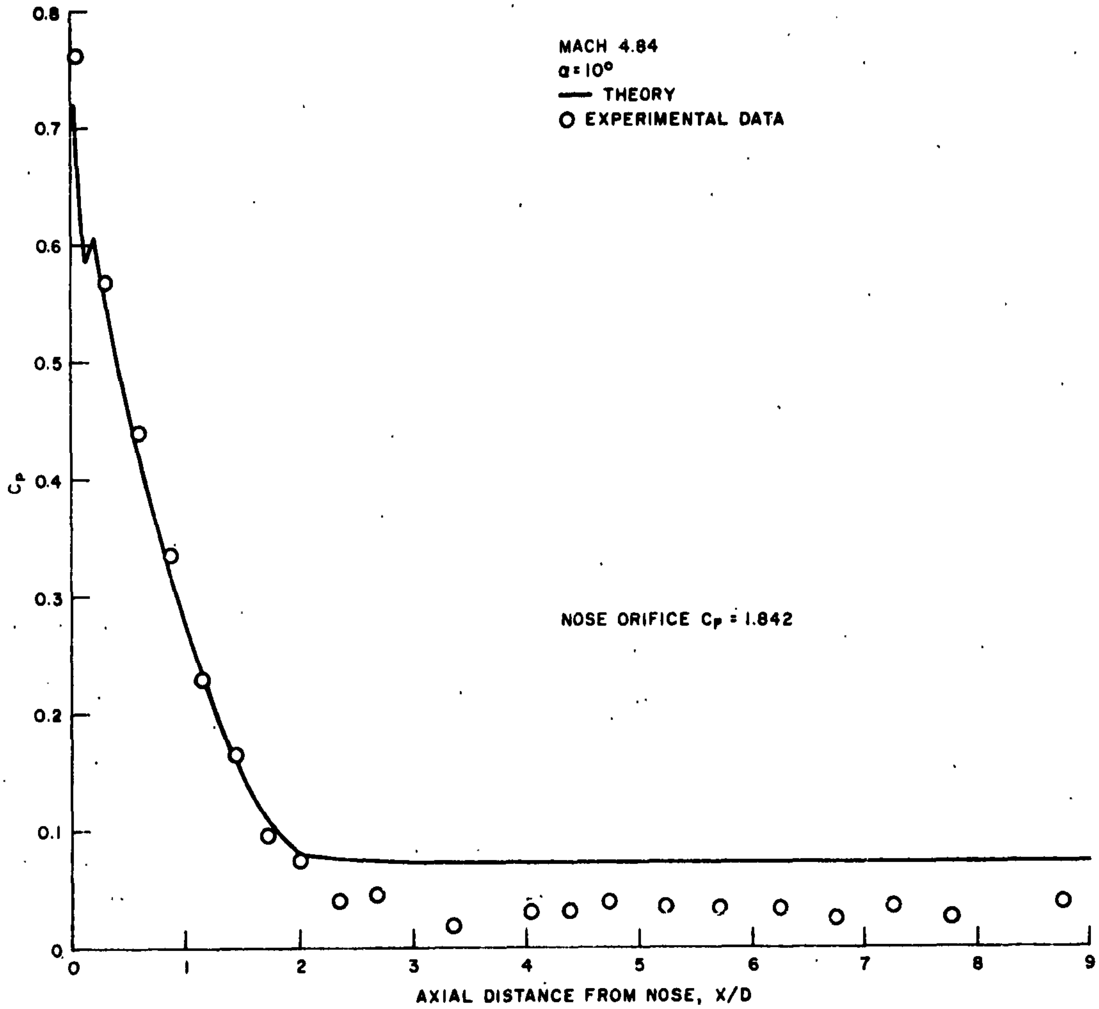

FIG. 9. Characteristics Solution Mach 4.84, α = 10°.

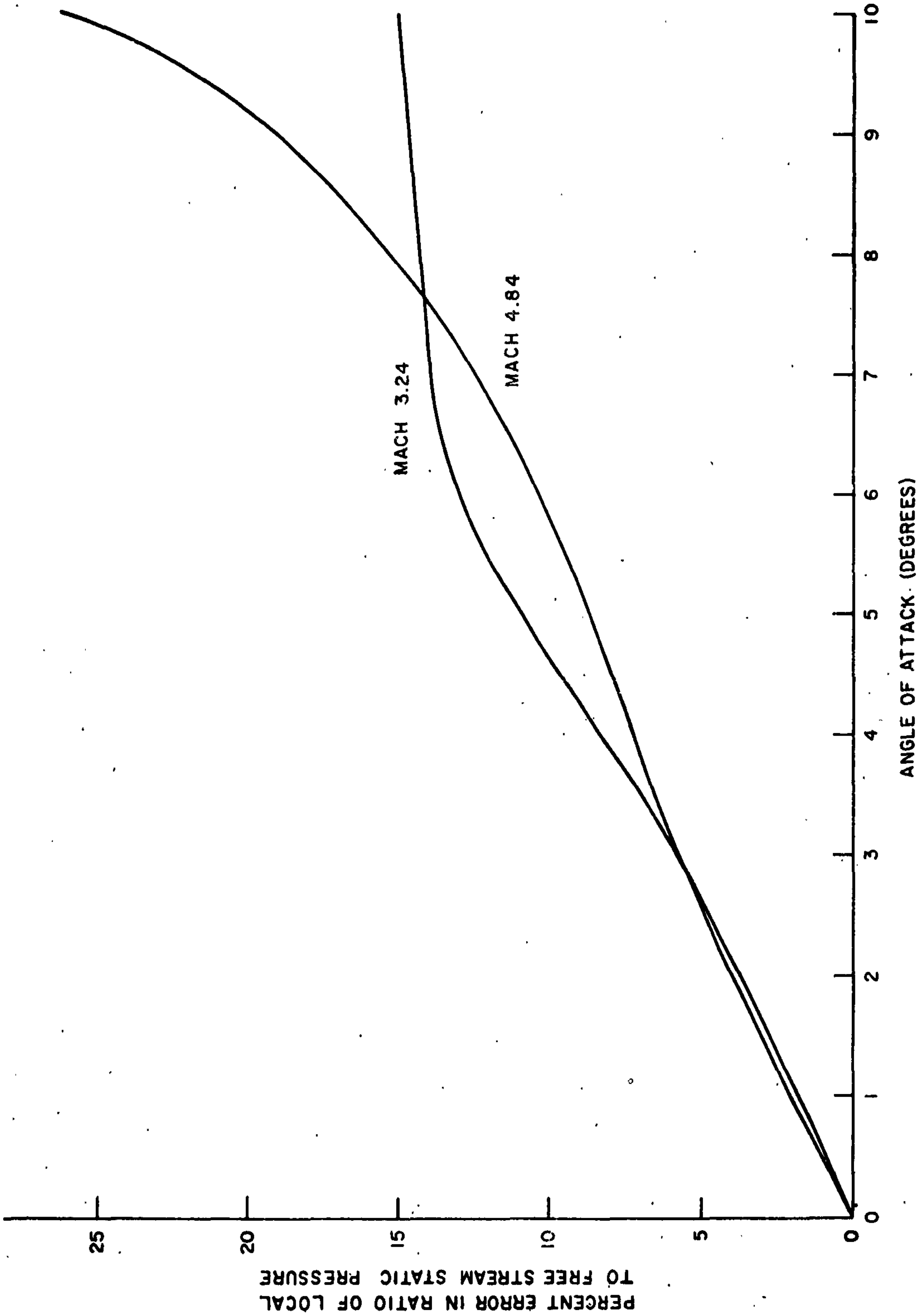

FIG. 10. Relative Error at Angle of Attack.

Appendix

PRESSURE DISTRIBUTION CURVES OF NOL WIND-TUNNEL TESTS

The experimental data curves shown in Fig. 11 through 17 constitute the remainder of the results which are presented in Ref. 1, but are not included in the preceding discussions. These additional data are presented here for the convenience of the readers since Ref. 1 was prepared for internal distribution at NOTS and is not generally available for reference purposes.

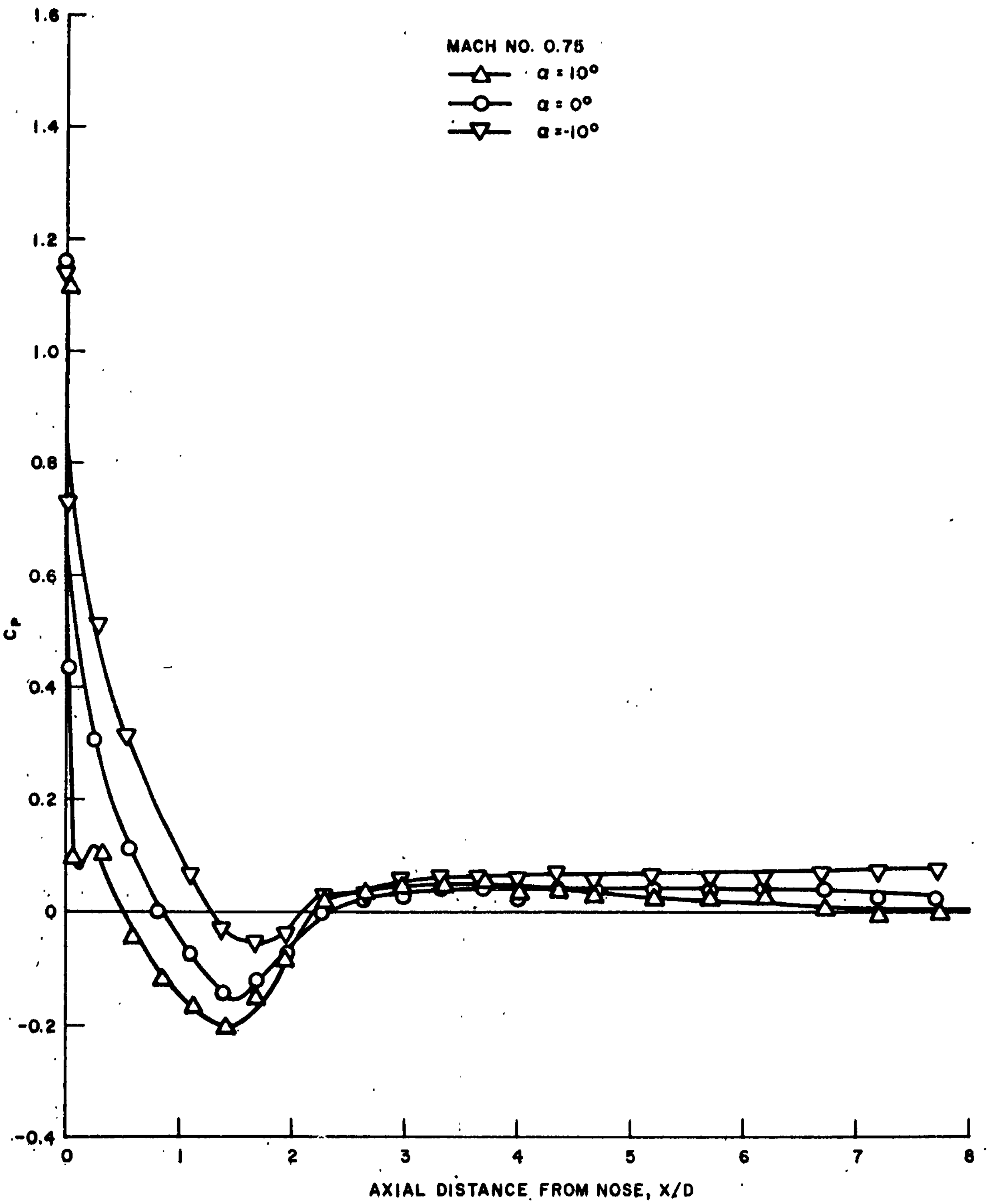

FIG. 11. Experimental Pressure Distribution Curves, M = 0.75.

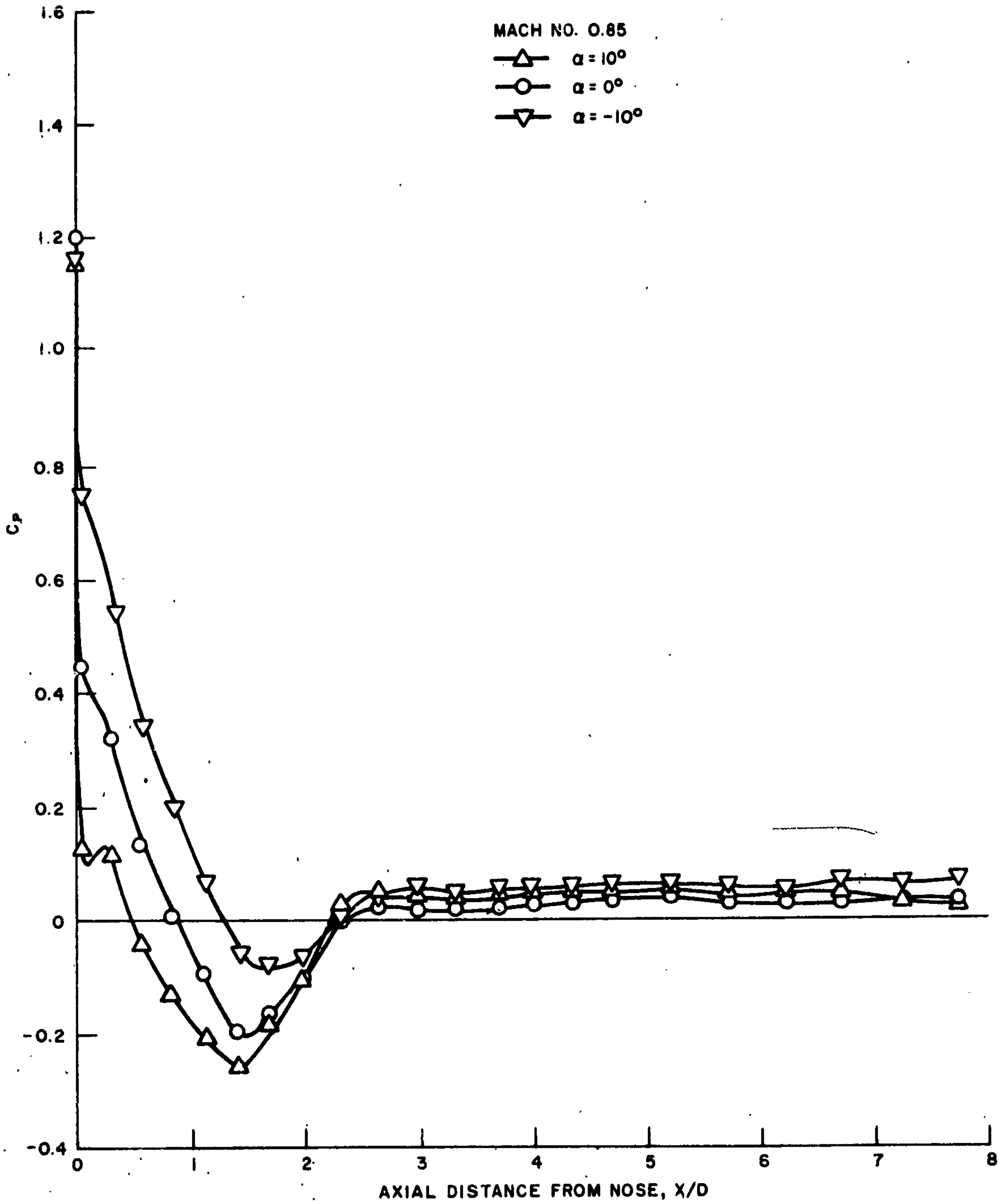

FIG. 12. Experimental Pressure Distribution Curves, M = 0.85.

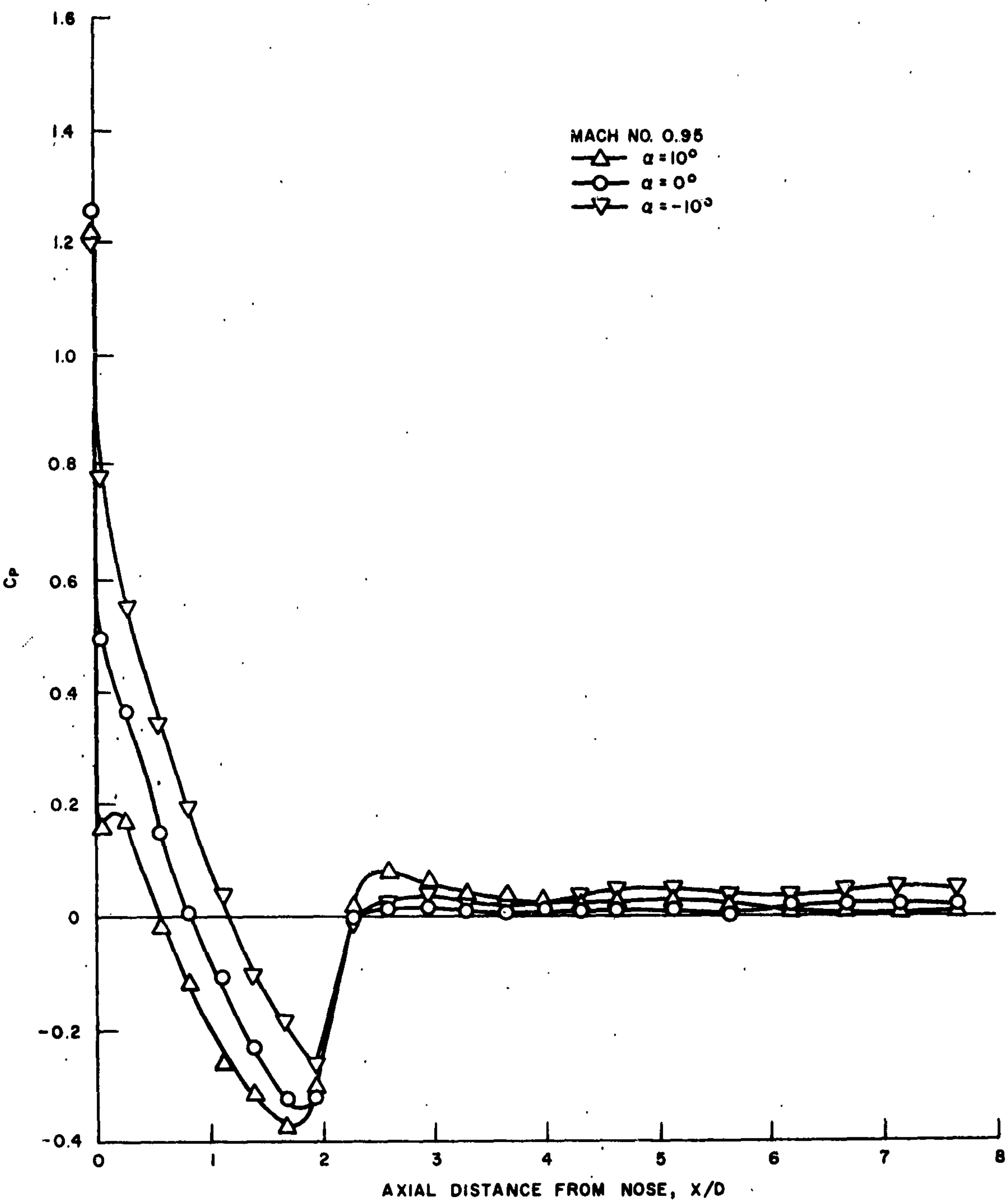

FIG. 13. Experimental Pressure Distribution Curves, M = 0.95

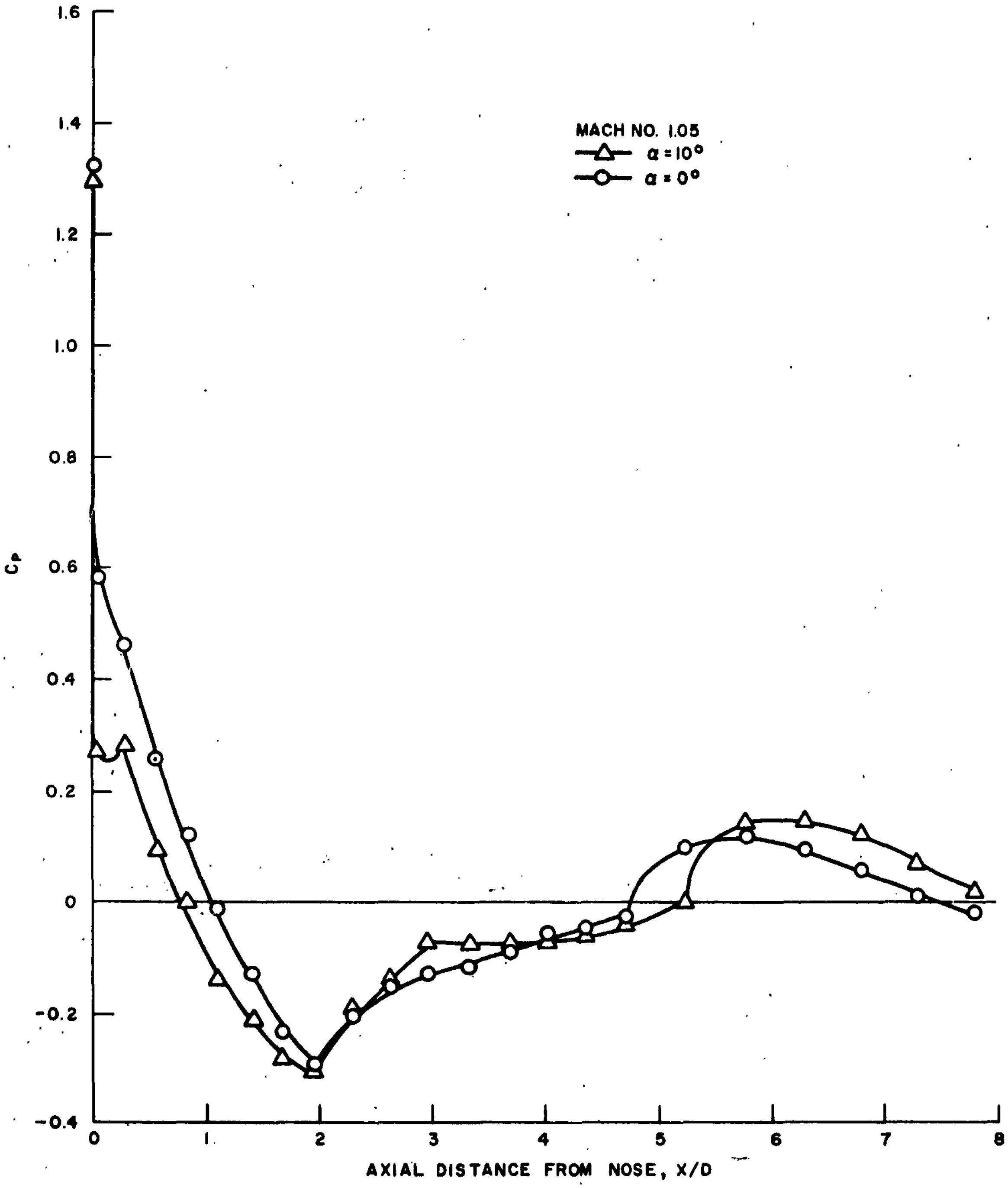

FIG. 14. Experimental Pressure Distribution Curves, M = 1.05.

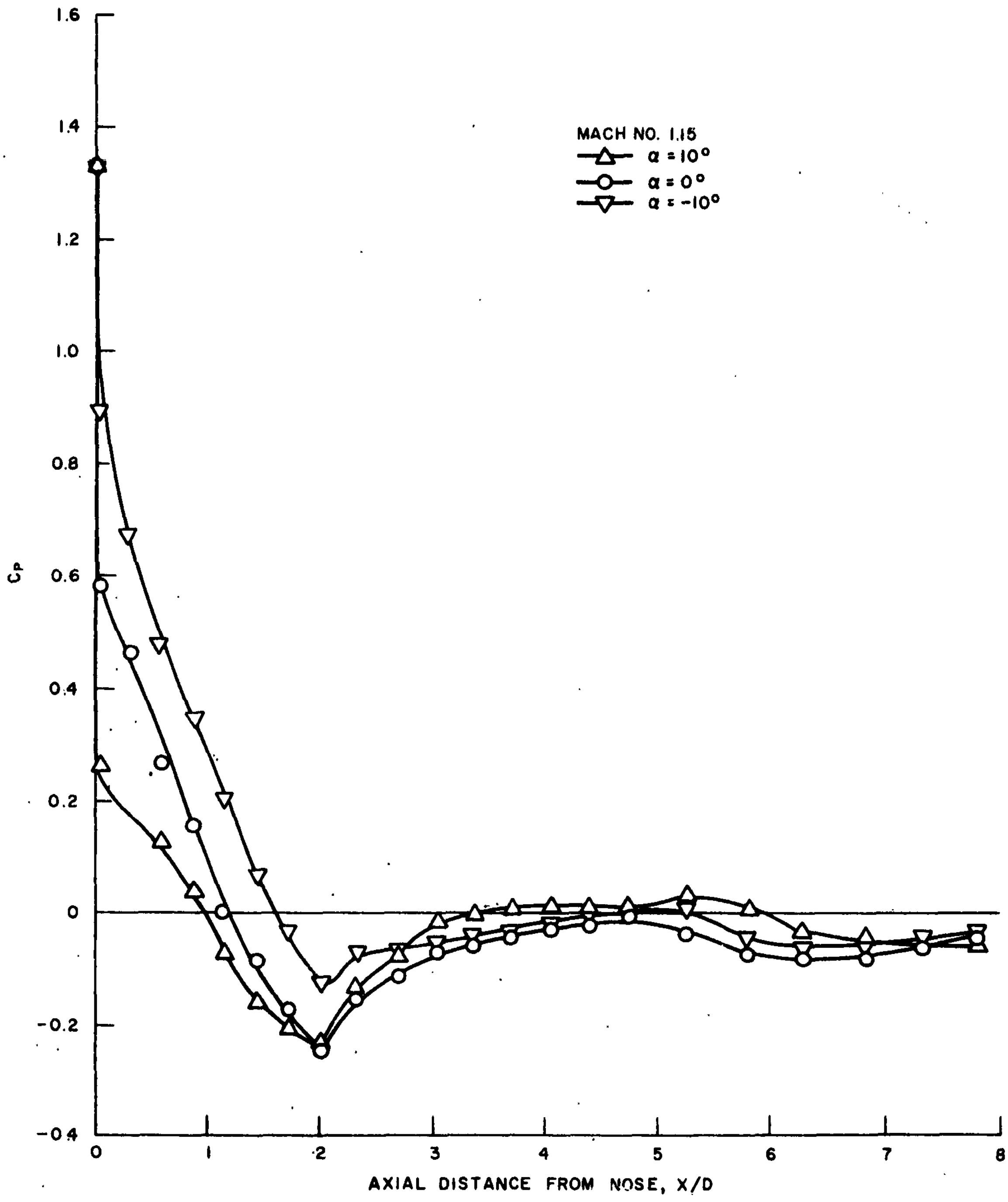

FIG. 15. Experimental Pressure Distribution Curves, M = 1.15.

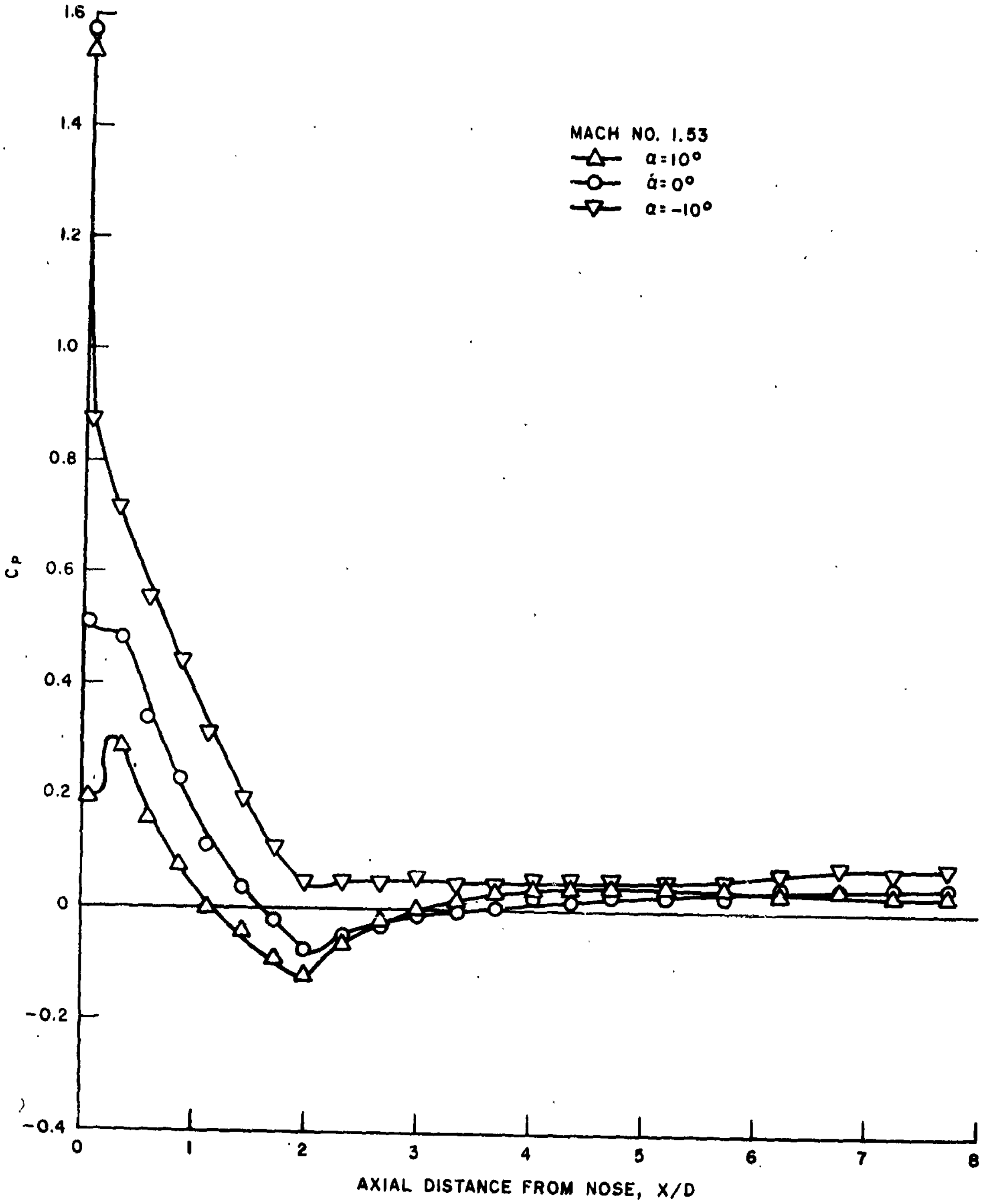

FIG. 16. Experimental Pressure Distribution Curves, M = 1.53.

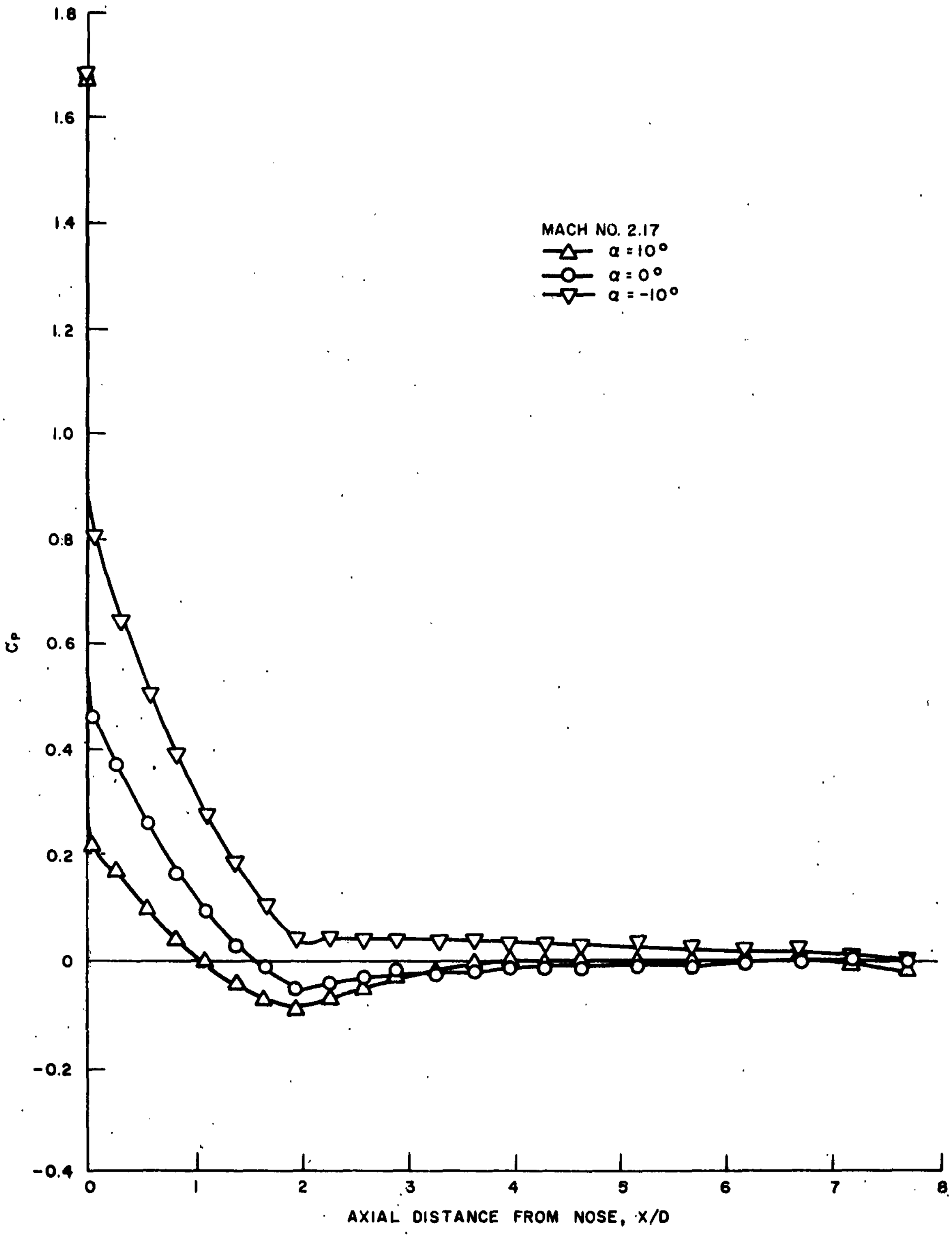

FIG. 17. Experimental Pressure Distribution Curves, M = 2.17.

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ABSTRACT CARD

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